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UTILITY  
PATENT APPLICATION  
TRANSMITTAL

(Only for new nonprovisional applications under 37 C.F.R. § 1.53(b))

Attorney Docket No. 9351-20/HSF  
First Inventor or Application Identifier Chen et al  
Title Catalytic Humidifier and Heater for the Fuel Stream of a Fuel  
Express Mail Label No.

## APPLICATION ELEMENTS

See MPEP chapter 600 concerning utility patent application contents.

ADDRESS TO: Assistant Commissioner for Patents  
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Washington, DC 20231

1. ☒ \* Fee Transmittal Form (e.g., PTO/SB/17)  
(Submit an original and a duplicate for fee processing)
2. ☒ Specification [Total Pages 17]  
(preferred arrangement set forth below)  
- Descriptive title of the invention  
- Cross References to Related Applications  
- Statement Regarding Fed sponsored R & D  
- Reference to Micro fiche Appendix  
- Background of the invention  
- Brief Summary of the invention  
- Brief Description of the Drawings (if filed)  
- Detailed Description  
- Claim(s)  
- Abstract of the Disclosure
3. ☒ Drawing(s) (35 U.S.C. 113) [Total Sheets 5]
4. Oath or Declaration [Total Pages 4]  
a. ☒ Newly executed (original or copy)  
b. ☐ Copy from a prior application (37 C.F.R. § 1.63(d))  
(for continuation/divisional with Box 16 completed)  
i. ☐ DELETION OF INVENTOR(S)  
Signed statement attached deleting inventor(s) named in the prior application, see 37 C.F.R. §§ 1.63(d)(2) and 1.33(b).

5. ☐ Microfiche Computer Program (Appendix)
6. Nucleotide and/or Amino Acid Sequence Submission (if applicable, all necessary)  
a. ☐ Computer Readable Copy  
b. ☐ Paper Copy (identical to computer copy)  
c. ☐ Statement verifying identity of above copies

## ACCOMPANYING APPLICATION PARTS

7. ☒ Assignment Papers (cover sheet & document(s))
8. ☐ 37 C.F.R. § 3.73(b) Statement of Power of Attorney (when there is an assignee)
9. ☐ English Translation Document (if applicable)
10. ☐ Information Disclosure Statement (IDS)/PTO-1449 ☐ Copies of IDS Citations
11. ☐ Preliminary Amendment
12. ☒ Return Receipt Postcard (MPEP 503) (Should be specifically itemized)
13. ☒ \* Small Entity Statement filed in prior application, Status still proper and desired (PTO/SB/09-12)
14. ☐ Certified Copy of Priority Document(s) (if foreign priority is claimed)
15. ☐ Other: \_\_\_\_\_

\* NOTE FOR ITEMS 1 & 13: IN ORDER TO BE ENTITLED TO PAY SMALL ENTITY FEES, A SMALL ENTITY STATEMENT IS REQUIRED (37 C.F.R. § 1.27), EXCEPT IF ONE FILED IN A PRIOR APPLICATION IS RELIED UPON (37 C.F.R. § 1.28).

16. If a CONTINUING APPLICATION, check appropriate box, and supply the requisite information below and in a preliminary amendment:

☐ Continuation ☐ Divisional ☐ Continuation-in-part (CIP) of prior application No: \_\_\_\_\_

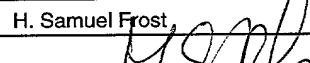
Prior application information: Examiner \_\_\_\_\_ Group / Art Unit: \_\_\_\_\_

For CONTINUATION or DIVISIONAL APPS only: The entire disclosure of the prior application, from which an oath or declaration is supplied under Box 4b, is considered a part of the disclosure of the accompanying continuation or divisional application and is hereby incorporated by reference. The incorporation can only be relied upon when a portion has been inadvertently omitted from the submitted application parts.

## 17. CORRESPONDENCE ADDRESS

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Applicant or Patentee: Chen et al.  
 Serial or Patent No.: n/a  
 Filed or Issued: Filed concurrently herewith  
 Title: Catalytic Humidifier and Heater for the Fuel Stream of a Fuel Cell

Attorney's  
 Docket No: 9351-20

**VERIFIED STATEMENT (DECLARATION) CLAIMING SMALL ENTITY STATUS**  
**(37 CFR 1.9(f) and 1.27 (c)) - SMALL BUSINESS CONCERN**

I hereby state that I am

- ☐ the owner of the small business concern identified below:  
☒ an official of the small business concern empowered to act on behalf of the concern identified below:

NAME OF CONCERN Hydrogenics Corporation  
 ADDRESS OF CONCERN 100 Caster Avenue, Woodbridge, Ontario, Canada L4L 5Y9

I hereby state that the above identified small business concern qualifies as a small business concern as defined in 13 CFR 121.3-18, and reproduced in 37 CFR 1.9(d), for purposes of paying reduced fees under section 41(a) and (b) of Title 35, United States Code, in that the number of employees of the concern, including those of its affiliates, does not exceed 500 persons. For purposes of this statement, (1) the number of employees of the business concern is the average over the previous fiscal year of the concern of the persons employed on a full-time, part-time or temporary basis during each of the pay periods of the fiscal year, and (2) concerns are affiliates of each other when either, directly or indirectly, one concern controls or has the power to control the other, or a third party or parties controls or has the power to control both.

I hereby state that rights under contract or law have been conveyed to and remain with the small business concern identified above with regard to the invention described in:

- ☒ the specification filed herewith with title as listed above.  
☐ the application identified above.  
☐ the patent identified above.

If the rights held by the above identified small business concern are not exclusive, each individual, concern or organization having rights to the invention is listed below\* and no rights to the invention are held by any person, other than the inventor, who would not qualify as an independent inventor under 37 CFR 1.9(c) if that person made the invention, or by any concern which would not qualify as a small business concern under 37 CFR 1.9(d), or a nonprofit organization under 37 CFR 1.9(e). \*NOTE: Separate verified statements are required from each named person, concern or organization having rights to the invention averring to their status as small entities. (37 CFR 1.27)

NAME \_\_\_\_\_ ADDRESS \_\_\_\_\_  
☐ INDIVIDUAL ☐ SMALL BUSINESS CONCERN ☐ NONPROFIT ORGANIZATION

I acknowledge the duty to file, in this application or patent, notification of any change in status resulting in loss of entitlement to small entity status prior to paying, or at the time of paying, the earliest of the issue fee or any maintenance fee due after the date on which status as a small entity is no longer appropriate. (37 CFR 1.28 (b))

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that those statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application, any patent issuing thereon, or any patent to which this verified statement is directed.

NAME OF PERSON SIGNING PIERRE RIVARD  
 TITLE OF PERSON IF OTHER THAN OWNER PRESIDENT & CEO  
 ADDRESS OF PERSON SIGNING 100 CASTER AVE, WOOD BRIDGE, ON  
 SIGNATURE [Signature] DATE 12 JUN 00

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Figure 1 consists of 11 sub-diagrams labeled (a) through (k), arranged vertically. Each diagram shows a different stage of a 3D model's construction. (a) is a simple wireframe of a head and neck. (b) adds a jaw and teeth. (c) adds a tongue. (d) through (k) show the addition of various facial features, including eyes, nose, mouth, and skin, leading to a more complete and realistic model.

UNITED STATES

**Title: CATALYTIC HUMIDIFIER AND HEATER FOR  
THE FUEL STREAM OF A FUEL CELL**

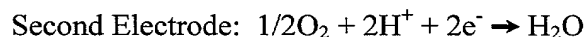
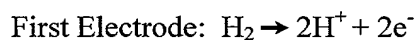
**FIELD OF THE INVENTION**

5           This invention relates to electrochemical fuel cells, more particularly electrochemical fuel cells which employ hydrogen as a fuel and receive an oxidant to convert the hydrogen to electricity and heat. This invention is even more particularly concerned with the humidification requirements of such an electrochemical fuel cell employing a proton exchange membrane.

10           **BACKGROUND OF THE INVENTION**

          Generally, a fuel cell is a device which converts the energy of a chemical reaction into electricity. It differs from a battery in that the fuel cell can generate power as long as the fuel and oxidant are supplied.

15           A fuel cell produces an electromotive force by bringing the fuel and oxidant into contact with two suitable electrodes and an electrolyte. A fuel, such as hydrogen gas, for example, is introduced at a first electrode where it reacts electrochemically in the presence of the electrolyte and catalyst to produce electrons and cations in the first electrode. The electrons are circulated from the first  
20   electrode to a second electrode through an electrical circuit connected between the electrodes. Cations pass through the electrolyte to the second electrode. Simultaneously, an oxidant, typically air, oxygen enriched air or oxygen, is introduced to the second electrode where the oxidant reacts electrochemically in presence of the electrolyte and catalyst, producing anions and consuming the  
25   electrons circulated through the electrical circuit; the cations are consumed at the second electrode. The anions formed at the second electrode or cathode react with the cations to form a reaction product, such as water. The first electrode or anode may alternatively be referred to as a fuel or oxidizing electrode, and the second electrode may alternatively be referred to as an oxidant or reducing electrode. The  
30   half-cell reactions at the two electrodes are as follows:



The external electrical circuit withdraws electrical current and thus receives electrical power from the cell. The overall fuel cell reaction produces electrical energy which is the sum of the separate half-cell reactions written above. Water and heat are typical by-products of the reaction.

5           In practice, fuel cells are not operated as single units. Rather, fuel cells are connected in series, stacked one on top of the other, or placed side by side. A series of fuel cells, referred to as fuel cell stack, is normally enclosed in a housing. The fuel and oxidant are directed through manifolds to the electrodes, while cooling is provided either by the reactants or by a cooling medium. Also within the stack  
10           are current collectors, cell-to-cell seals and insulation, with required piping and instrumentation provided externally to the fuel cell stack. The stack, housing, and associated hardware make up the fuel cell module.

          Fuel cells may be classified by the type of electrolyte, which is either liquid or solid. The present invention is primarily concerned with fuel cells using a  
15           solid electrolyte, such as a proton exchange membrane (PEM). The PEM has to be kept moist with water because the available membranes will not operate efficiently when dry. Consequently, the membrane requires constant humidification during the operation of the fuel cell, normally by adding water to the reactant gases, usually hydrogen and air.

20           The proton exchange membrane used in a solid polymer fuel cell acts as the electrolyte as well as a barrier for preventing the mixing of the reactant gases. An example of a suitable membrane is a copolymeric perfluorocarbon material containing basic units of a fluorinated carbon chain and sulphonic acid groups. There may be variations in the molecular configurations of this membrane.  
25           Excellent performances are obtained using these membranes if the fuel cells are operated under fully hydrated, essentially water-saturated conditions. As such, the membrane must be continuously humidified, but at the same time the membrane must not be over humidified or flooded as this degrades performances. Furthermore, the temperature of the fuel cell stack must be kept above freezing in order to  
30           prevent freezing of the stack.

          Cooling, humidification and pressurization requirements increase the cost and complexity of the fuel cell, reducing its commercial appeal as an

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alternative energy supply in many applications. Accordingly, advances in fuel cell research are enabling fuel cells to operate without reactant conditioning, and under air-breathing, atmospheric conditions while maintaining usable power output.

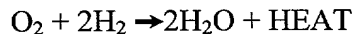
5 The current state-of-the-art in fuel cells, although increasingly focusing on simplified air-breathing, atmospheric designs, has not adequately addressed operations in sub-zero temperatures, which requires further complexity in the design. For instance, heat exchangers and thermal insulation are required, as are additional control protocols for startup, shut-down, and reactant humidifiers.

10 Where a solid polymer proton exchange membrane (PEM) is employed, this is generally disposed between two electrodes formed of porous, electrically conductive material. The electrodes are generally impregnated or coated with a hydrophobic polymer such as polytetrafluoroethylene. A catalyst is provided at each membrane/electrode interface, to catalyze the desired electrochemical reaction, with a finely divided catalyst typically being employed. The membrane/electrode  
15 assembly is mounted between two electrically conductive plates, each which has at least one fluid flow passage formed therein. The fluid flow conductive fuel plates are typically formed of graphite. The flow passages direct the fuel and oxidant to the respective electrodes, namely the anode on the fuel side and the cathode on the oxidant side. The electrodes are electrically connected in an electric circuit, to  
20 provide a path for conducting electrons between the electrodes. In a manner that is conventional, electrical switching equipment and the like can be provided in the electric circuit as in any conventional electric circuit. The fuel commonly used for such fuel cells is hydrogen, or hydrogen rich reformat from other fuels (“reformat” refers to a fuel derived by reforming a hydrocarbon fuel into a gaseous  
25 fuel comprising hydrogen and other gases). The oxidant on the cathode side can be provided from a variety of sources. For some applications, it is desirable to provide pure oxygen, in order to make a more compact fuel cell, reduce the size of flow passages, etc. However, it is common to provide air as the oxidant, as this is readily available and does not require any separate or bottled gas supply. Moreover, where  
30 space limitations are not an issue, e.g. stationary applications and the like, it is convenient to provide air at atmospheric pressure. In such cases, it is common to simply provide channels through the stack of fuel cells to allow for flow of air as

the oxidant, thereby greatly simplifying the overall structure of the fuel cell assembly. Rather than having to provide a separate circuit for oxidant, the fuel cell stack can be arranged simply to provide a vent, and possibly some fan or the like to enhance air flow.

5 Catalytic burners are also known and operate on a principle similar to fuel cells, but at an accelerated kinetic rate and increased temperature. A fuel, for example hydrogen, is oxidized through direct contact with oxygen or air at a rate induced by the presence of a catalytic bed, for example, ceramic beads containing small amounts of platinum on the surface.

10 The by-product of the chemical reaction is similar to that of a fuel cell, but without any generation of electricity:



The higher consumption rate of the reactants and concomitant heat release reflects the fact that the reaction occurs through direct contact rather than through a proton/electron transaction. Catalytic burning is flameless, and occurs at a temperature between that of a fuel cell's "cold combustion" and that of an open-flame combustion. Flow rate can be pulsed or modulated to achieve varying heat and moisture profiles. Hydrogen catalytic burning requires no pilot flame or spark to be initiated.

20 An example of a proposal for a catalytic burner is found in an article entitled "Catalytic Combustion of Hydrogen in a Diffusive Burner" by K. Stephen and B. Dahm at pages 1483 - 1492 of Catalytic Combustion of Hydrogen in a Diffusive Burner.

## 25 SUMMARY OF THE INVENTION

In the prior art, humidification through membrane stack provided humidification only, without imparting significant temperature shift. In the present invention, both humidification and temperature are imparted to the stream prior to admission to the stack.

30 In accordance with a first aspect of the present invention, there is provided a tubular reactor, for catalyzing reaction of hydrogen and a gaseous oxidant, the tubular reactor comprising:

an elongated housing, a catalyst formed from a material adapted to promote catalytic combustion of the fuel and the oxidant, being formed into an elongated body substantially filling the elongate housing and being porous, a first inlet for a gaseous fuel and a second inlet for a gaseous oxidant, both first and second inlets being provided at one end of the elongated housing;

and an outlet at the other end of the housing, whereby, in use, the catalyst promotes combustion between the fuel and the oxidant to generate heat and moisture, whereby a heated and humidified gas flow exits through the outlet.

Preferably, the housing and the body of the catalyst are both generally cylindrical and have length substantially longer than the diameter than the tubular reactor.

In accordance with a second aspect of the present invention, there is provided a fuel cell system comprising at least one fuel cell, each fuel cell comprising:

an inlet for a fuel;

an anode having a catalyst associated therewith for producing cations from the fuel;

a fuel manifold, connected between the inlet and the anode, for distributing fuel to the anode;

an oxidant inlet means for supplying oxidant;

a cathode having a catalyst associated therewith and connected to the oxidant inlet means, for producing anions from the oxidant, said anions reacting with said cations to form water on said cathode;

an ion exchange membrane deposited between said anode and said cathode, said membrane facilitating migration of cations from said anode to said cathode, while isolating the fuel and the oxidant from one another;

a catalytic reactor having a first inlet for fuel and a second inlet for an oxidant, and an outlet for heated and humidified gas, the catalytic reactor being mounted to supply the heated and humidified gas to the fuel cell.

Preferably, the fuel cell system comprises a plurality of fuel cells, forming a fuel cell stack.



The stack can comprise an air-breathing stack, including a plurality of channels extending through the fuel cell stack for permitting free flow of ambient air as the oxidant through the fuel cell stack, there being at least one channel for each fuel cell, wherein the catalytic reactor is mounted below the fuel cell stack.

5 The catalytic converter is configured to receive air as an oxidant through the second inlet thereof in excess of the stoichiometric quantity of air required for combustion of fuel within the catalytic reactor, whereby heated and humidified air is discharged from the outlet of the catalytic reactor. The outlet of the catalytic reactor is mounted below the channels of the fuel cell stack, whereby heated and moistened air flows  
10 upwardly through the channels of the fuel cell stack from the catalytic reactor.

The catalytic reactor can be either generally tubular or it can be disk-shaped, configured for flow of fuel and oxidant generally along the central axis of the reactor.

A further aspect of the present invention provides a method of operating  
15 a fuel cell system comprising a plurality of fuel cells, each fuel cell comprising an inlet for fuel, an anode having a catalyst associated therewith for producing cations from fuel, a fuel manifold connected between the inlet and the anode for distributing fuel to the anode, an oxidant inlet means for supplying oxidant, a cathode having a catalyst associated therewith and connected to the oxidant inlet  
20 means for producing anions from the oxidant, said anions reacting with said cations to form water on said cathode and an ion exchange membrane disposed between the anode and the cathode, for facilitating migration of cations from the anode to the cathode, while isolating the fuel and oxidant from one another, the method comprising

- 25 (a) supplying oxidant and fuel to the fuel cell for reaction to generate electrical power and heat;
- (b) supplying fuel to the catalytic reactor and oxidant to the catalytic reactor, in an amount greater than the stoichiometric amount required for the combustion of the fuel, to ensure complete combustion of the fuel, thereby  
30 generating a flow of heated and humidified oxidant;
- (c) supplying the heated and humidified oxidant to the fuel cell, for reaction with the fuel to generate electricity and heat.

For initial start-up below a preset temperature, the method can comprise initially supplying fuel and oxidant only to the catalytic reactor to generate a flow of heated and moistened oxidant, and passing the heated and moistened oxidant through the fuel cell to preheat the fuel cell, and commencing supply of fuel to the fuel cell, once the fuel cell reaches a desired temperature. Then, after start-up and after the fuel cell has reached the desired temperature, a sufficient quantity of the oxidant and the fuel are supplied to the reactor, to maintain the oxidant supplied to the fuel cell system at a desired humidity level.

Yet another aspect of the present invention provides a method of operating a fuel cell system comprising a plurality of fuel cells, each fuel cell comprising an inlet for fuel, an anode having a catalyst associated therewith for producing cations from fuel, a fuel manifold connected between the inlet and the anode for distributing fuel to the anode, an oxidant inlet means for supplying oxidant, a cathode having a catalyst associated therewith and connected to the oxidant inlet means, for producing anions from the oxidant, said anions reacting with said cations to form water on said cathode and an ion exchange membrane disposed between the anode and the cathode, for facilitating migration of cations from the anode to the cathode, while isolating the fuel and the oxidant from one another, the method comprising:

- (a) supplying oxidant and fuel to the fuel cells for reaction to generate electrical power and heat;
- (b) supplying fuel to the catalytic reactor and oxidant to the catalytic reactor, in an amount less than the stoichiometric amount required for combustion of fuel, to ensure complete consumption of the oxidant, thereby generating a flow of heated and humidified fuel;
- (c) supplying the heated and humidified fuel to the fuel cell, for reaction with oxidant known to generate electricity and heat.

This aspect of the method can include:

- (a) providing a second catalytic reactor;
- (b) supplying the second reactor with fuel and oxidant in an amount greater than the stoichiometric amount required for combustion of fuel, thereby generating a flow of heated and humidified oxidants; supplying the heated

and humidified oxidant to the oxidant inlet means of the fuel cell, for reaction with a heated and humidified fuel to generate electricity and heat. In the prior art, humidification through membrane stacks provided humidification only, without imparting a significant temperature shift. In this invention, both humidity and temperature are imparted to the stream prior to admission to the stack.

### **BRIEF DESCRIPTION OF THE DRAWING FIGURES**

For a better understanding of the present invention and to show more clearly how it may be carried into effect, reference will now be made, by way of example, to the accompanying drawings which show a preferred embodiment of the present invention and in which:

Figure 1 is a schematic view of the first embodiment of a fuel cell system in accordance with the present invention;

Figure 2 is a schematic view of a second embodiment of a fuel cell system in accordance with the present invention;

Figures 3a and 3b are, respectively, perspective and side views of a tubular reactor in accordance with the present invention;

Figure 4 is a plan view of part of the fuel cell stack of Figures 1 and 2; and

Figure 5 is a more detailed view of the second embodiment of the fuel cell system shown in Figure 2.

### **DESCRIPTION OF THE PREFERRED EMBODIMENT**

Referring first to Figure 1, the first embodiment of the apparatus is indicated generally by the reference 10 and includes an enclosure 12, in the apparatus. In the drawings, this is identified as a HyTef-FC15 Enclosure.

Within the enclosure 12, there is a fuel stack 14 comprising, in known manner, a plurality of PEM fuel cells, and described in greater detail in relation to Figure 4. For the stack 14, a main fuel supply line 16 is provided for hydrogen. The fuel line 16 extends into the enclosure 12 and continues as a main supply line 18 including a respective flow control valve 24 and a solenoid-operated valve 25. As shown, a stack purge outlet at 26 enables excess hydrogen to be purged from the

fuel cell stack 14. A respective solenoid controlled valve 27, controls purging of the hydrogen gas. Again, as is known, this prevents accumulation of contaminants and impurities in the hydrogen fuel, within the fuel cell stack 14. The purged hydrogen through the purge outlet 26 can be recycled for consumption.

5           The fuel cell stack 14 in Figure 1 is a closed stack. Hydrogen fuel flows through the anode side of each individual fuel cell in known manner. Correspondingly, an air inlet 34 is provided, connected to an air line 38. A pump 36 for the air is provided, and an air exhaust indicated at 43.

10           In accordance with the present invention, the fuel or hydrogen supply line 16 is connected to a catalytic reactor 50, which includes a catalytic reactor bed 57 (Figure 3), comprising, for example reticulated aluminum; this material is chosen for its thermal conductivity, cost and ease of use. A separate air inlet 41 is provided, connected via a pump 40 and an air supply line 42 to the catalytic reactor 50. Non-return valves 58 prevent back flow of air and fuel, and a flash arrestor 59 is  
15           provided for the fuel cell.

          The catalytic reactor 50 is generally tubular, has respective inlets 52 and 54 for hydrogen and air, and a tubular outlet 56. A flow of heated, humidified fuel exits from the tubular outlet 56, and will then flow to the fuel inlet of the fuel cell stack.

20           Reference will now be made to Figure 2, which shows a third embodiment of the present invention. This embodiment of the invention again can have an enclosure, as indicated at 60, and again includes a fuel cell stack, here indicated at 62. The stack 62 here is a closed stack, and is provided with an air pump or blower 64 connected by a main supply line 66 to an inlet of the fuel cell  
25           stack 62, and excess air exhausts from the fuel cell stack 62 as indicated at 68.

          On the hydrogen side, a hydrogen supply line 70 can include a pressure gauge and a flow meter (not shown), and comprises a main hydrogen supply line 72 to the fuel cell stack 62 and a secondary supply line 74 to the catalytic burner or reactor. A solenoid valve 73 is provided in the main supply line 72, and a solenoid  
30           valve 75, a flash arrestor 76 and a non-return valve 77 are provided in the secondary line 74. A fuel purge valve 78 with a controlling solenoid valve 79 are provided as for the first embodiment.

The tubular, catalytic reactor 50 is again provided and the hydrogen inlet 52 is again provided at the side of the reactor.

An air supply line for the catalytic reactor 50 is indicated at 80 and includes a pump or meter 82, and a respective non-return valve 84. The air supply  
5 line 80 is connected to a respective inlet 54. Optionally, a pressure gauge and a flow meter can be provided.

The outlet 56 of the tubular reactor 50 is connected by a line 85, to two branch lines 86 and 87, which are connected by respective solenoid valves 88 and 89 to the supply line 72 and to the air supply line 66. Although not shown, the stack  
10 62 can optionally include a recirculation pump. Excess hydrogen can, in a known manner, be purged through the outlet 68 or purge line 78, to prevent build-up of contaminants.

The tubular reactor 50 can be run to provide either a humidified and heated flow of air or a humidified and heated flow of hydrogen. These two modes  
15 of operation are detailed below.

To generate a flow of heated and humidified air, excess air is delivered by the pump 82, relative to the hydrogen flow through the line 74. In the tubular reactor 50, the oxygen reacts with the hydrogen to generate heat and moisture. This results in a heated and moistened air flow exiting through the outlet 56. Then, the  
20 valve 88 is maintained closed and the valve 89 is opened, so that the heated and moistened air flow passes through to the main air supply line 66, to be entrained into the air flow passing to the fuel cell stack 62.

Correspondingly, to generate a heated hydrogen flow, the valve 88 is opened and the valve 89 closed. Then, excess hydrogen is supplied through the line  
25 74, as compared to air supplied through the main fuel line 82. The flow is dead ended and is only exhausted during purging when the exhaust solenoid is open. However, the flow can be controlled using control valves when not operated in dead-ended mode. In the tubular reactor 50, the oxygen in the air reacts with some of the hydrogen to generate heat and moisture. The flow of hydrogen, with residual  
30 nitrogen, together with heat and moisture, then exits from the outlet 56. This flow of heated and humidified nitrogen and hydrogen gas passes through valve 88 into the main fuel line 72.

It will be appreciated that where heated and humidified hydrogen is supplied to the fuel line 72, and as air is used as the oxidant, this does result in nitrogen being injected into the fuel gas supply. For this reason, the purge line 78 will need to be used, to prevent the build-up of nitrogen within the fuel cell stack 62. Alternatively, a flowing system can be used at all times.

It is important that, in the tubular, catalytic reactor 50, complete reaction takes place. In other words, it is essential that, in the two modes of operation, residual hydrogen is not delivered to the main air line 66, nor residual oxygen delivered to the hydrogen supply line 72. This could result in potentially flammable gas mixtures of hydrogen and oxygen being delivered to the fuel cell stack 62, which is dangerous. To ensure complete reaction, proper topology and morphology of the reactor must be designed, essentially to ensure adequate residence time over the full range of flow rates.

It will also be understood that it is possible to heat and humidify both of the fuel and air supply lines. Because of the different requirements of the two supply lines, this would require the provision of two separate tubular reactors, each of which would be configured to operate in one of the two modes outlined above.

Turning to Figure 3, this shows, in detail, the tubular reactor 50. It is to be appreciated that this is an early version of the tubular reactor 50, and in particular, the housing of the tubular reactor 50 is made from conventional, off-the-shelf components. It is anticipated that the overall configuration of the tubular reactor 50 can be enhanced to give a design which both has better performance characteristics, and is more economical to manufacture.

The tubular reactor 50 comprises a tubular reactor housing 51. At the lower end thereof, a T-connector 100 is provided. The T-connector 100 has three coupling flanges 102, one of which is connected to the tubular housing 51, and the two others of which provide connections for the hydrogen supply lines. At the top end, the tubular reactor 50 includes a connector 104, again provided with connection flanges 106, one of which is connected to the tubular housing 51 and the others of which provide connections to supply lines. While a housing 51 of circular cross-section is shown, it will be understood that any suitable cross-section, for example a square cross-section, could be used.

15

**CLAIMS:**

1. A tubular reactor, for catalyzing reaction of hydrogen and a gaseous oxidant, the tubular reactor comprising:
- 5 an elongated housing,
- a catalyst formed from a material adapted to promote catalytic combustion of the fuel and the oxidant, being formed into an elongated body substantially filling the elongated housing and being porous, a first inlet for a gaseous fuel and a second inlet for a gaseous oxidant, both first and second inlets
- 10 being provided at one end of the elongated housing; and
- an outlet at the other end of the housing, whereby, in use, the catalyst promotes combustion between the fuel and the oxidant to generate heat and moisture, whereby a heated and humidified gas flow exits through the outlet.
- 15 2. A tubular reactor as claimed in claim 1, wherein the housing and the body of the catalyst are both generally cylindrical and have a length substantially longer than the diameter thereof.
3. A tubular reactor as claimed in claim 1 or 2, which includes, for the first
- 20 and second inlets, fittings for connection to supply lines for fuel and the oxidant, and for the outlet, a fitting for connection to a conduit for receiving the heated, humidified gas flow.
4. A fuel cell system comprising:
- 25 at least one fuel cell, each fuel cell comprising:
- a main fuel inlet;
- an anode having a catalyst associated therewith for producing cations from the fuel;
- a fuel manifold, connected between the main fuel inlet and the anode,
- 30 for distributing fuel to the anode;
- an oxidant inlet means for supplying oxidant;



a cathode having a catalyst associated therewith and connected to the oxidant inlet means, for producing anions from the oxidant, said anions reacting with said cations to form water on said cathode;

5 an ion exchange membrane deposited between said anode and said cathode, said membrane facilitating migration of cations from said anode to said cathode, while isolating the fuel and the oxidant from one another; and

10 a catalytic reactor having a first inlet for fuel and a second inlet for an oxidant, and an outlet for heated and humidified fuel, the catalytic reactor being connected to the main fuel inlet, whereby, in use, with fuel and oxidant supplied to the catalytic reactor and the fuel being supplied in excess of the stoichiometric amount, heated and humidified fuel is supplied from the catalytic reactor to the main fuel inlet.

5. A fuel cell system as claimed in claim 4, which includes a plurality of  
15 fuel cells forming a fuel cell stack, which includes a main fuel inlet connected to all of the inlets of the fuel cells.

6. A fuel cell system as claimed in claim 4 or 5 wherein the catalytic  
20 reactor is generally tubular.

7. A fuel cell system as claimed in claim 5 wherein the outlet of the  
catalytic reactor is connected by a first control valve to the main fuel inlet of the fuel cell stack and by a second control valve to the oxidant inlet means whereby, in use, the outlet of the catalytic reactor can be selectively connected to one of the  
25 main fuel inlet and the oxidant inlet means, with supply of the oxidant as the fuel to the catalytic reactor adjusted so that the heated and humidified gas at the outlet of the catalytic reactor includes an excess of gas corresponding to said one of the main fuel inlet and the oxidant inlet means.

30 8. A fuel cell system as claimed in claim 7, which includes a fuel supply line connected to the catalytic reactor and an air supply line connected to the

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catalytic reactor, each of the fuel supply line and the air supply line including, at least one of a pressure gauge, a flow meter and a non-return valve.

9. A fuel cell system as claimed in claim 5, wherein the oxidant inlet  
5 means comprises an air distribution manifold within the fuel cell stack for distributing air, as the oxidant, to individual fuel cells, wherein a main air supply line is provided connected to the air distribution manifold.

10. A fuel cell system as claimed in claim 9, wherein the fuel cell stack  
10 includes a fuel outlet and means for recirculating fuel from the fuel outlet to the fuel inlet.

11. A fuel cell system as claimed in claim 10, wherein the catalytic reactor  
15 is provided in the main air supply line, and wherein a second catalytic reactor is provided in the fuel supply line and a secondary air supply line connects the main air supply line to the secondary catalytic reactor, for a supply of air in an amount less than the stoichiometric amount required for combustion of fuel, whereby, the secondary catalytic reactor generates heated and humidified fuel.

12. A fuel cell system as claimed in claim 11, where each of the first and  
20 second catalytic reactors is generally tubular.

13. A method of operating a fuel cell system comprising a plurality of fuel  
25 cells, each fuel cell comprising an inlet for fuel, an anode having a catalyst associated therewith for producing cations from fuel, a fuel manifold connected between the inlet and the anode for distributing fuel to the anode, an oxidant inlet means for supplying oxidant, a cathode having a catalyst associated therewith and connected to the oxidant inlet means for producing anions from the oxidant, said anions reacting with said cations to form water on said cathode and an ion exchange  
30 membrane disposed between the anode and the cathode, for facilitating migration of cations from the anode to the cathode, while isolating the fuel and oxidant from one another, the method comprising

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16. A method as claimed in claim 15, which includes: supplying air as the oxidant; providing the fuel cell system as an air-breathing system including vertical channels for flow of air as the oxidant; and providing only a portion of the air required as the oxidant through the catalytic reactor, with additional air flowing directly through the channels of the fuel cell system.

Figure 1 consists of 12 sub-diagrams labeled (a) through (l), arranged vertically. Each diagram shows a different stage in the construction of a 3D structure, likely a protein or a complex molecule. The diagrams use various symbols: solid lines for the main structure, dashed lines for connections or bonds, and arrows to indicate the direction of assembly or the path of a component. Labels (a) through (l) are placed to the right of each corresponding diagram. The sequence starts with a simple rectangular frame in (a) and progressively adds more complex elements, including internal connections and additional structural layers, until the final, more complete structure is shown in (l).

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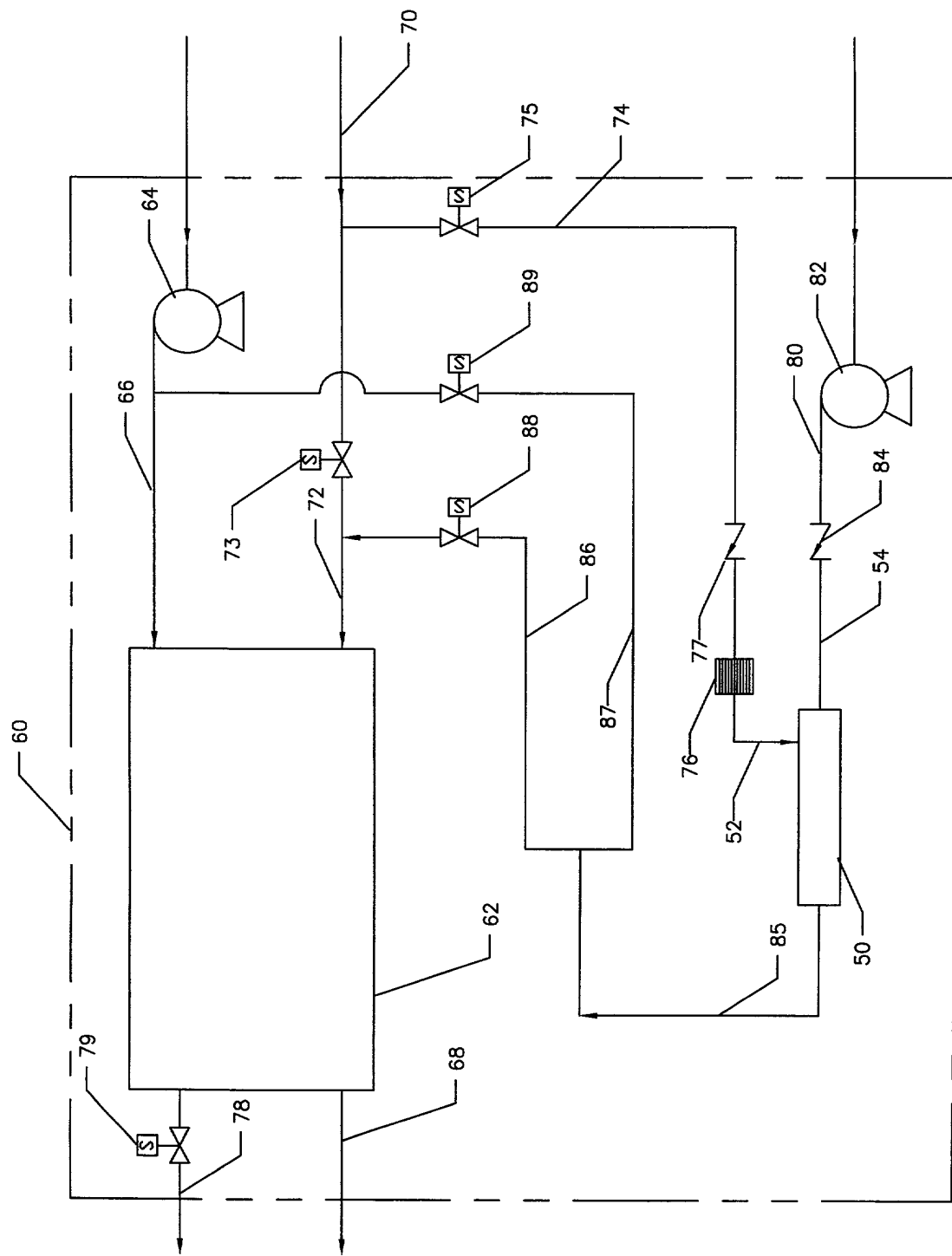
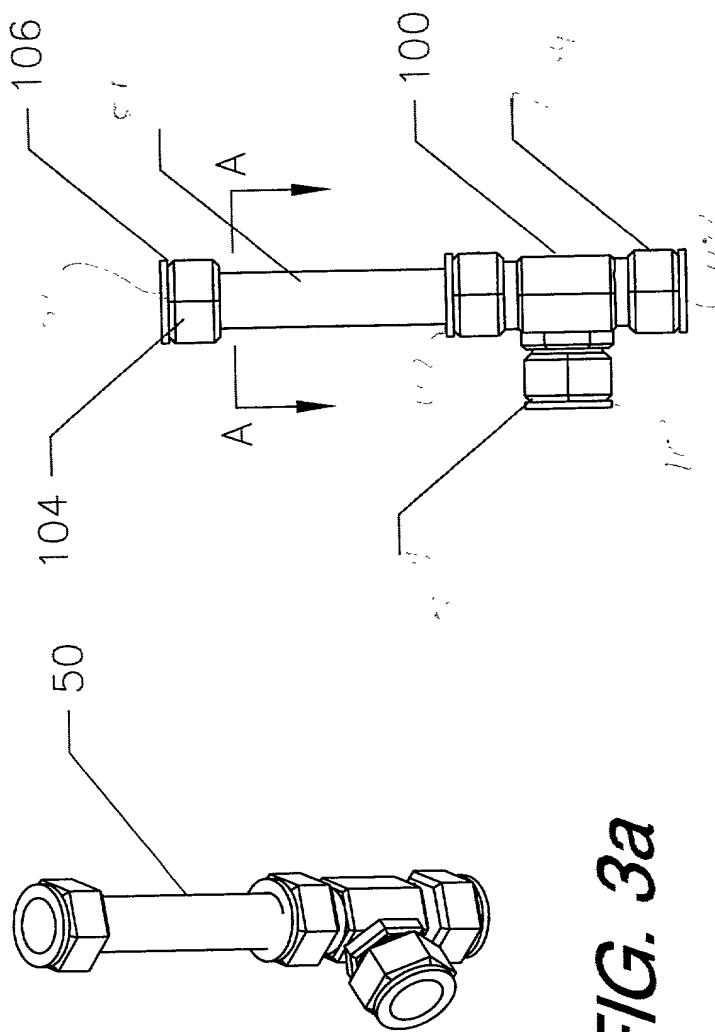
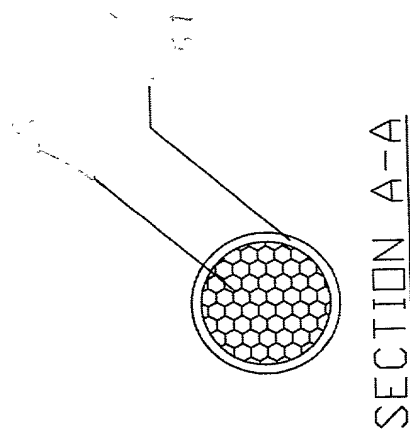


FIG. 2



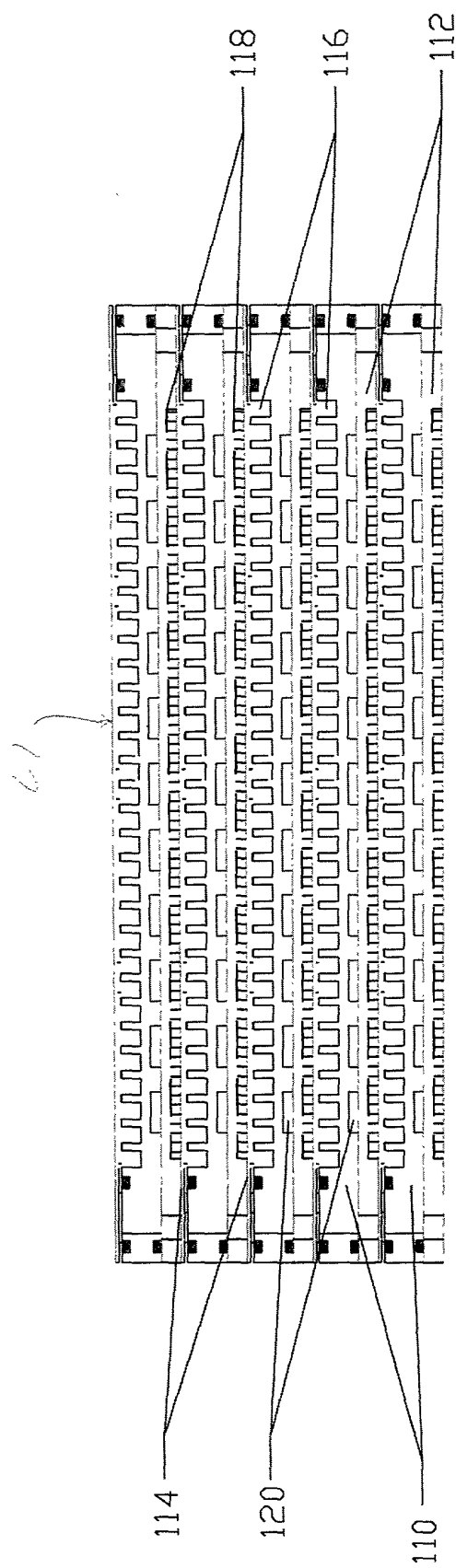
**FIG. 3a**



SECTION A-A

**FIG. 3b**

**FIG. 3C**

[illegible]

**FIG. 4**



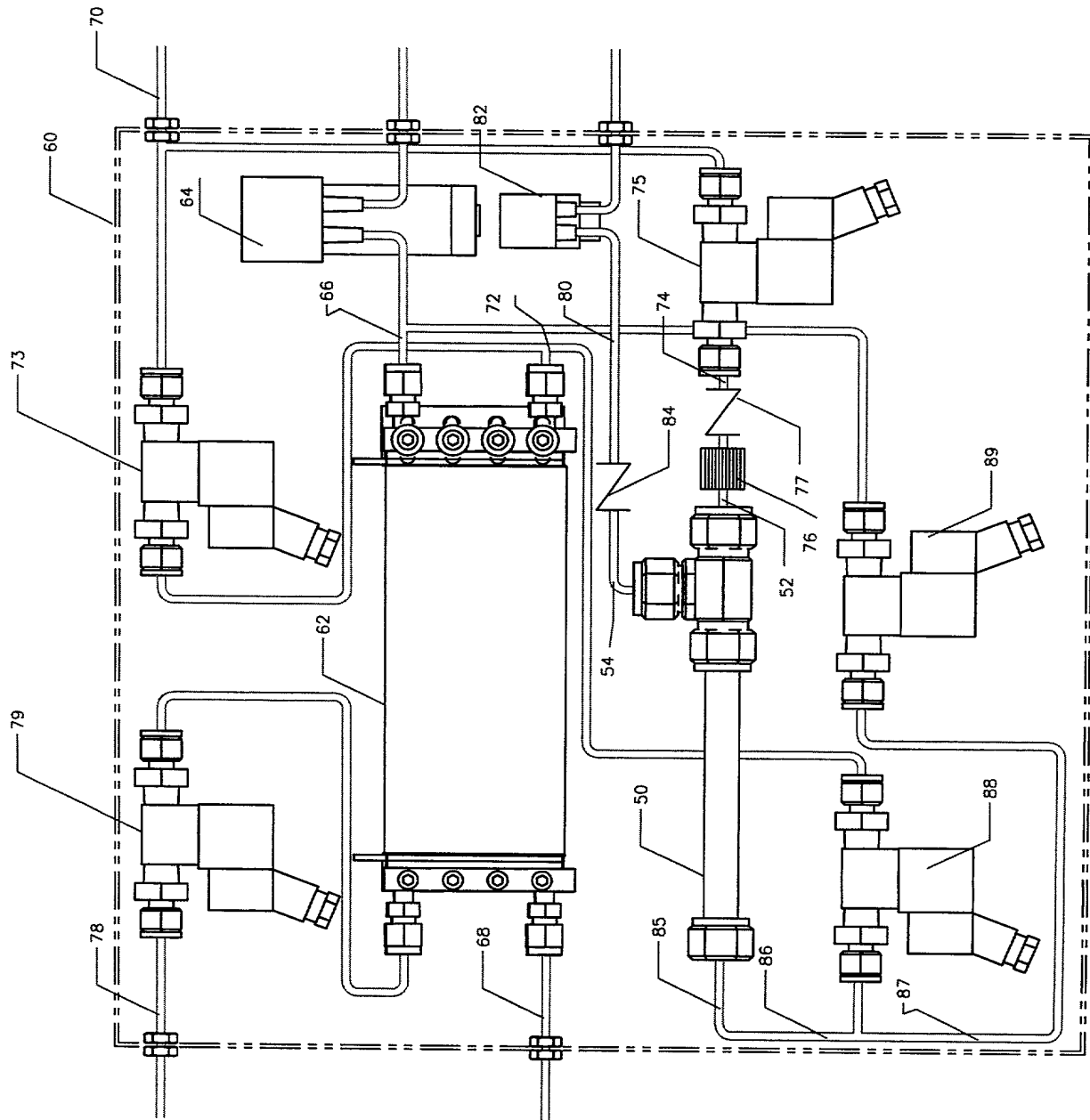


FIG. 5

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## DECLARATION FOR UTILITY OR DESIGN PATENT APPLICATION (37 CFR 1.63)

☒ Declaration Submitted with Initial Filing OR ☐ Declaration Submitted after Initial Filing (surcharge (37 CFR 1.16 (e)) required)

Attorney Docket Number	9351-20/HSF
First Named Inventor	Chen et al.
<b>COMPLETE IF KNOWN</b>	
Application Number	n / a
Filing Date	Filed concurrently herewith
Group Art Unit	n/a
Examiner Name	n/a

As a below named inventor, I hereby declare that:

My residence, post office address, and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

CATALYTIC HUMIDIFIER AND HEATER FOR THE FUEL STREAM OF A FUEL CELL

the specification of which ☒ is attached hereto (Title of the Invention)  
OR

☐ was filed on (MM/DD/YYYY) as United States Application Number or PCT International

Application Number and was amended on (MM/DD/YYYY) (if applicable).

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment specifically referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR 1.56.

I hereby claim foreign priority benefits under 35 U.S.C. 119(a)-(d) or 365(b) of any foreign application(s) for patent or inventor's certificate, or 365(a) of any PCT international application which designated at least one country other than the United States of America, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or of any PCT international application having a filing date before that of the application on which priority is claimed.

Prior Foreign Application Number(s)	Country	Foreign Filing Date (MM/DD/YYYY)	Priority Not Claimed	Certified Copy Attached?	
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			<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
			<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

☐ Additional foreign application numbers are listed on a supplemental priority data sheet PTO/SB/02B attached hereto:

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Application Number(s)	Filing Date (MM/DD/YYYY)	
		<input type="checkbox"/> Additional provisional application numbers are listed on a supplemental priority data sheet PTO/SB/02B attached hereto.

[Page 1 of 2]

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I hereby claim the benefit under 35 U.S.C. 120 of any United States application(s), or 365(c) of any PCT international application designating the United States of America, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of 35 U.S.C. 112, I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR 1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application.

U.S. Parent Application or PCT Parent Number	Parent Filing Date (MM/DD/YYYY)	Parent Patent Number (if applicable)

☐ Additional U.S. or PCT international application numbers are listed on a supplemental priority data sheet PTO/SB/02B attached hereto.

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Richard J. Parr	22,836	Philip Mendes da Costa	33,106
H. Roger Hart	26,426	Robert B. Storey	33,108
David W.R. Langton	27,747	John R. Rudolph	38,003
C. Lloyd Sarginson	29,245	Robin L.A. Coster	38,016
Timothy J. Sinnott	31,083	Michael E. Charles	38,036

☒ Additional registered practitioner(s) named on supplemental Registered Practitioner Information sheet PTO/SB/02C attached hereto.

Direct all correspondence to: ☒ Customer Number **1059** OR ☐ Correspondence address below

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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under 18 U.S.C. 1001 and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Name of Sole or First Inventor: ☐ A petition has been filed for this unsigned inventor

Given Name (first and middle (if any)) Family Name or Surname

Xuesong Chen

Inventor's Signature *Chen Xuesong* Date *06/04/00*

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☒ Additional inventors are being named on the supplemental Additional Inventor(s) sheet(s) PTO/SB/02A attached hereto

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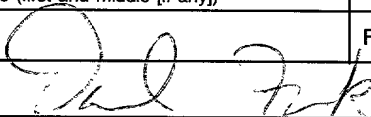
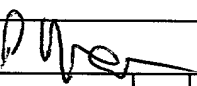
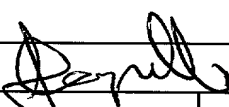
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## DECLARATION

## ADDITIONAL INVENTOR(S) Supplemental Sheet

Page 1 of 1

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David				Frank			
Inventor's Signature						Date	06/06/00
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Post Office Address	same						
City	Scarborough	State	Ontario	ZIP	M1S 2S7	Country	Canada
<b>Name of Additional Joint Inventor, if any:</b>		<input type="checkbox"/> A petition has been filed for this unsigned inventor					
Given Name (first and middle [if any])				Family Name or Surname			
Pierre				Rivard			
Inventor's Signature						Date	6/6/00
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Post Office Address	113 Hove Street						
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Given Name (first and middle [if any])				Family Name or Surname			
Joe				Cargnelli			
Inventor's Signature						Date	6/6/00
Residence: City	Toronto	State	Ontario	Country	Canada	Citizenship	Canadian
Post Office Address	59 Lapp Street						
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